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Discharge Characteristics of Bucket Elevator under varying Parameters

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Abstract---Bucket elevators are widely used to lift material at various heights. Granular material is one of the common types of material handled by the bucket elevators. One of the major criteria for design of elevator is the discharge from the elevator. It has been observed that discharge from bucket elevators depends on factors like linear speed of bucket, shape of bucket, radius for the discharge side sprocket and more. [14] The mathematical equation is developed by equating the forces acting on a particle at the tip of bucket and determining the parameters values at which the particle will fly off. It was observed that while using maize as material handled, bucket linear speed 2 m/sec and bucket wheel radius 0.12m whereas material is placed at 0.162 m then discharge of material begins at 42.84 ^{0} . [21] The results of presented model give the angle at which discharge starts, using measurable angle of bucket and position of grain with respect to center of sprocket; and angle where the friction force component acts using position of grain and selected angle to determine discharge. Hence, this paper incorporates the method to calculate the angle at which discharge will begin by using the fixed characteristics of the Elevator.

Key Words--- Bucket elevator, bucket wheel, centrifugal force

I. INTRODUCTION

As material handling equipment bucket elevators are highly effective to handle different materials, it will be quite useful to establish mathematical relation exhibiting discharge at every progressive angle. Mass flow rate is function of angle of discharge, so to establish required relationship it is needed to evaluate role of angle of repose on bulk material to flow, dependency of physical dimensions of bucket shape, the angle of discharge from chute and size of discharge trajectory. Considering the focus of this research work is to predict the angle measured with respect to horizontal plane, at which the granular and non-sticky material will start to fly off the bucket; It is observed that this angle depends on various parameters like force, linear speed of bucket, shape of bucket, radius for the discharge side sprocket and more. Finally, an equation is developed based on the free Body Diagram for the same. It can be seen that the force balance equation derived from the Free Body Diagram which enables to determine the angle at which the particle from bucket will start escaping. This work will help to improve the efficiency of discharge rate that can be achieved for different combinations of parameters.

II. LITERATURE REVIEW

Keni'iti Minamiodi, et al. [1] have shown that in context with discharge efficiency bucket's top and bottom angle are very important and shown experimental parabolic trajectory of grains.

Koster [2] has used pole method and tried to improve basic calculations of discharge by considering centrifugal and gravity discharge process and shown path of parabolic trajectory of discharged point mass located in center of gravity of bucket.

Rademacher [3] has discussed about discharge phenomenon with an analytical approximation for simple case of bucket field with cohesive material and did deep analysis of force based on consideration as free flowing material and point mass material.

Drazen [4] has correlated all different parameters to calculate the transport volume of bucket elevator and can provide hourly amount of discharge material for initial specifications.

Hauffstengel [5] has initiated the theory for what exactly happens to material when transported to bucket elevator to improve the equipment efficiency.

A. Katterfield & T. Donohue [6] have described computer simulations based on Discrete Element Method (DEM) for

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optimization of technical systems in field of mechanical conveying and calibrated DEM parameters to obtain results. Helmut [7] has proposed approximation software to calculate material throw trajectory with respect to different shape and size of buckets.

Krause F. & Kattefeld A. [8] have observed material dynamic flow in 3D and evaluated elevator on different speeds to optimize capacity during method of discharge and filling.

Beumer, B. & Wehmeier [9] have presented the role of internal and external friction between bucket surface and particulate.

Zegzulka, J. [10] have examined flow mechanisms like direct filling and scooping of particles in different conditions.

Gelnar, et al. [11] have experimented validation of bucket with the help of different particle quantity and standardize shape of bucket.

Mcbride, et al. [12] have presented discrete element model in bucket elevator's transition zone with DEM approach.

K.E.Ileleji & B. Zhou[13] have described experimental set up to measure angle of repose of bulk corn stover particles.

Hastie et al. [14] have presented profile of conveyor trajectories and simplify it with graphical analysis among various parameters.

Garic S. [15] has described deep bucket as most adequate from all size for high speed centrifugal discharge and provide formula to find bucket volume.

Nenad Miloradovic, et al. [16] have explained Finite element analysis of bucket and modeling to increase discharge of bucket elevator using adequate software.

Mustafa, et al. [17] showed, a modified path matrix approach which was presented in order to compare all the distinct geared kinematic mechanisms. A new method based on the matrix approach and corresponding train values is required to identify isomorphism among epicyclic gear trains and their mechanisms.

Mustafa, et al. [18] This is a novel, simple algorithm and less computation required to detect the duplication of EGTs. The proposed algorithm is applied to various examples from 4-links, 5-links, 6-links, and 8-links 1-DOF of the epicyclic gear trains, which helps to determine the relation between theoretical calculation and present machinery.

Mustafa, et al. [19] It is basically based on the connectivity matrices and the absolute sum of polynomial coefficient which identifying isomorphism in EGTs. Finally, the proposed method was examined on the basis of various examples from 4, 5, 6, and 8-links one-dof and 6-links two-dof EGTs, which envelopes the idea of defining coefficient to set the parameters.

N. K. Maurya, et al. [20] they have used additive manufacturing techniques to find the correlation of the properties using computational analysis and then comparing it with the experimental results.

Harichandra K. Chavhan, et al. [21] they worked on the load carrying capacity of the elevator bucket. Another aim is the relief of strain on the bucket lead edges and the clamping bolts. Bucket elevators always display problems when under harsh operating conditions, or build up (in the case of sticky bulk materials) are encountered. In order to avoid these problems high capacity bucket is designed to carry higher loads. Which was to be achieved from finite element approach.

Snehal, Patel, et al. [22] they worked on the Design and Analysis of different part of Bucket elevators‖, Failure of shaft is the main reason for the failure of bucket. In this paper shaft analysis is done and material is updated to avoid the failure.

Edward Yin, et al. [23] Their study was to reduce the production down time it is necessary to replace chain links as soon as possible as it caused the loss of productivity. To study this chemical and Metallurgical analysis is carried out.

Ghazi Abu Taher, et al. [24] They found that the Belt conveyor and Bucket elevator which is used to move the material from one point to other point. In this paper mainly the difference between both this technique is carried out with the experimentation.

N, Yashaswini, et al. [25] They studied the Design and Optimization of bucket elevator using FEA‖ analysis, they designed the bucket to carry materials at a height of 10m. Bucket is designed in NX software.

III. MATHEMATICAL FORMULATION

A. Assumptions

Assumptions made while formulating mathematical model are as follows:

a. All particles of the bulk material are of same size.
b. All particles have same topography in all direction.
c. The flow from the chute is frictionless.
d. The RPM of the sprocket in the prototype is constant hence, the angular velocity is constant.

B. Equations

Consider a situation where material is falling from the chute at some angle into the bucket of a centrifugal bucket elevator and then is discharged to some place. The time interval of 0.07 seconds is allowable at the bucket linear speed of 2 m/s to fill the bucket; so the chute is designed to maintain the bucket filling factor of 0.75. To vary discharge, the angle of discharge from the chute is to be varied; so the initial angle of discharge of chute is taken as 23^0 [13] same as the angle of repose of the maize grain. Table 1.

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Represents the increasing value of angle of chute and mass flow rate at it.

By increasing the height of the base, the angle is increased; the angle of discharge from chute is calculated. The mass flow rate is measured by weighing the discharge from the chute in monitored amount of time.

The formula to find angle of discharge through chute is

$$23 + \tan^{-1}\left(\frac{h}{L}\right) \tag{1}$$

SR NO:	Angle of chute and Discharge Comparison	
	Angle of chute (in Degrees)	***Discharge (in grams/sec)***
1.	27.87	450
2.	31.69	600
3.	34.63	670
4.	37.82	760
5.	52	980

TABLE 1. Chute angle and its corresponding discharge.

Using Standard bucket size from the CatLog and 2mm thick GI sheet the bucket, transparent on its sides is made, to trace the trajectory of the discharge in bucket elevator. The dimensions were traced onto it using the mallet and wooden blocks. A single bucket, bucket elevator is taken as a prototype which can be operated manually and can also be motorized.

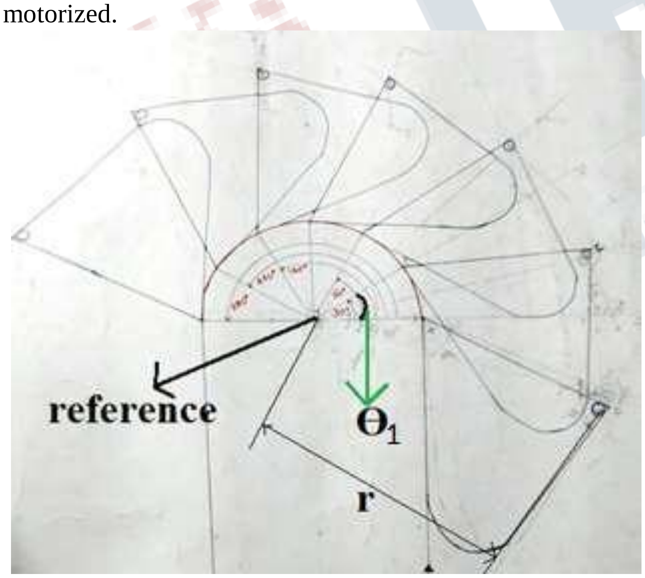

Fig.1 Angles in the bucket

$$\Theta = (b1+b2) + \tan^{-1}\left(\frac{}{K}\right) - 90^\circ \tag{2}$$

$$\Theta = 80 - \gamma \tag{3}$$

$$\alpha = \Theta_1 - \tan^{-1}\left(\frac{}{K}\right) \tag{4}$$

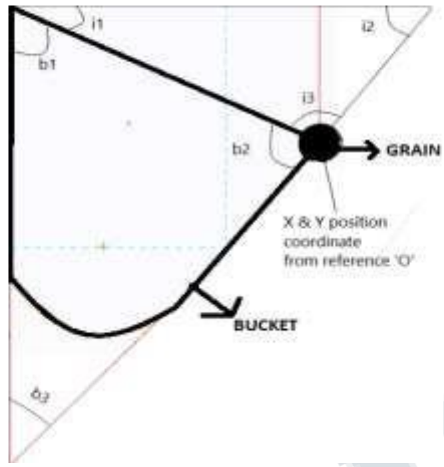

Fig.2 Arrangement at which the analysis is done

There are three forces acting on maize grain which is at the end of the bucket namely centrifugal force which is pushing the grain in radial direction, gravitational force which is pulling the grain towards ground and friction force between maize grain and bucket inner surface.

There are three forces acting on maize grain which is at the end of the bucket namely centrifugal force which is pushing the grain in radial direction, gravitational force which is pulling the grain towards ground and friction force between maize grain and bucket inner surface.

Component of Centrifugal Force acting on grain

$= m * r * m^2 * \cos\theta$ (5)

Total resisting force = component of gravitational force + component of frictional force

Hence Resisting Forces = $m*g*\sin\alpha + \mu * m*g*\cos\alpha$ (6)

Net Force F

$= m * r * \omega^2 * \cos\theta - m*g*\sin\alpha - \mu * m*g*\cos\alpha.$ (7)

And by using equations (4), (5) and (6) we can say that the condition for fly off is when

Centrifugal force > Resisting force

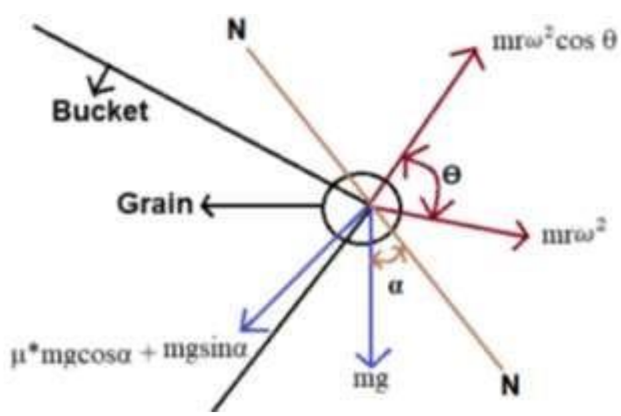

Fig.3 Direction of forces acting on grain

$$m * r * \omega^2 * \cos\theta > m*g*\sin\alpha + \mu * m*g*\cos\alpha. \quad (8)$$

Using the approach used in [2], To find the angle at which discharge, the centrifugal force and Resisting force are considered in equilibrium and direct force is considered;

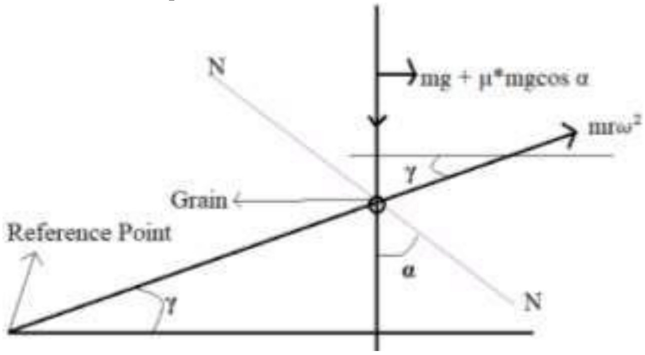

Fig.4 force triangle relation to find angle at which discharge begins

Hence,

$$\text{Sin}\,\gamma = \frac{\text{Resisting force}}{\text{Centrifugal force}} = \frac{m*g + \mu*m*g*\cos a}{m*r*\omega^2} \quad (9)$$

$$\gamma = \sin^{-1}\left(\frac{*}{r*\omega^2}\right) \quad (10)$$

IV. EXPERIMENTATION

Fig. 5 Experimental setup

Experiments were carried out on a setup as shown in Fig.5. A chute is used to discharge the material with the cross section 0.07m*0.1m into the collector bucket.

The maize grains are provided through the chute into the bucket with the angle of chute being 52^0 and the discharge is video graphed and then it is projected on a paper as shown in Fig.6 and then the discharge is measured by weighing the material discharge and dividing it by the density of dry corn i.e.720 kg/m^3 and then it is finally divided by the time frame in which the discharge is measured. Keeping the speed constant at 120 RPM and bucket filling factor of 0.75 and then observation is made on what kind of path the grains are travelling after being centrifugally discharged.

The next phase of the project is creating a mathematical model and using the model finding the values of the start angle of discharge and forces acting on it.

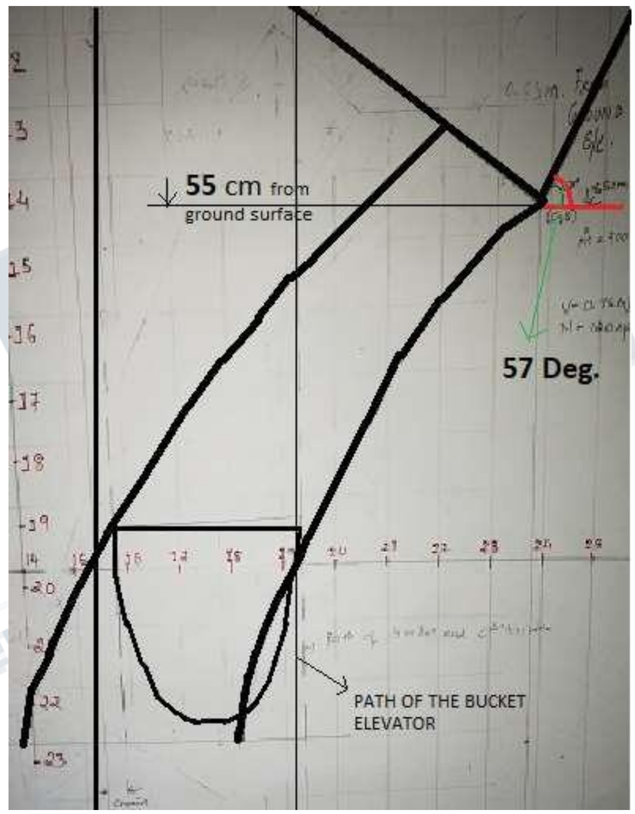

Fig.6 Flow rate: 1kg/s(appx) projected on paper

By using Equation (10) the graphs in Fig.7 and Fig.8 are generated. In Fig.7 two conditions are shown; Orange Curve is obtained by putting measured 'μ' value in the equation (10) and varying the velocity from 1 m/s to 2m/s and similarly the Blue Curve is obtained by putting 'μ' value as '0 (zero)', to obtain respective value of Angle at which Discharge begins; Whereas in Fig.8 the Orange Curve is obtained by putting measured 'μ' in the Equation (10) and varying the distance of the material from the reference point in the range of (0.1m to 0.25m) and the Blue Curve is obtained by putting 'μ' value as '0 (zero)', to obtain respective value of Angle at which Discharge begins.

V. DISCUSSION

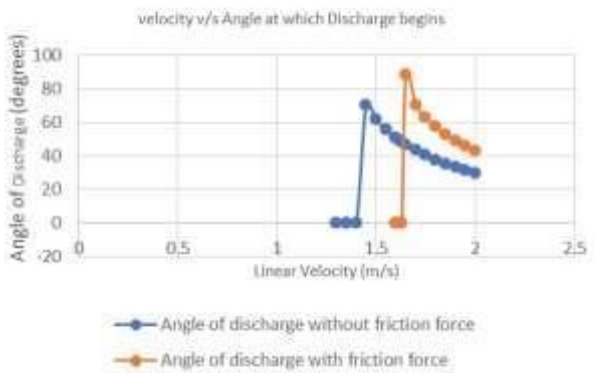

Fig.7 Velocity v/s Angle at which Discharge begins

It can be observed in Fig.7 that considering friction force as a part of resisting force, if the velocity drops less than 1.65 m/s then there will be no discharge; similarly, if friction force is not considered then the minimum or limiting value of velocity is 1.45 m/s

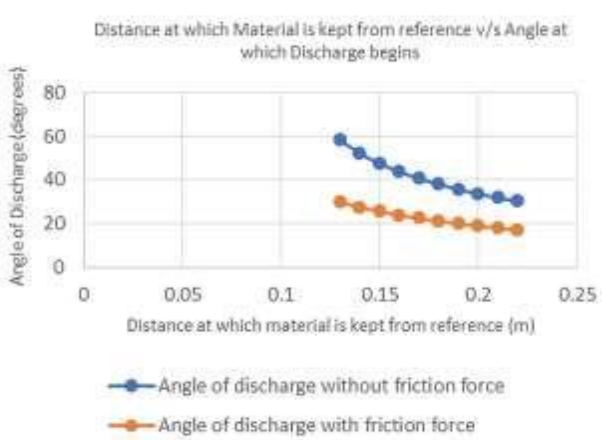

Fig.8 Distance at which Material is kept from reference v/s Angle at which Discharge begins

It can be observed in Fig.8 that considering friction force as a part of resisting force or if friction force is not considered as a part of resisting force still the trends observed by both the lines is same.

By considering the forces in equilibrium and their geometrical relation with the angle, at which discharge begins can be calculated,

 $\gamma = 42.84^{0}$

Based on this value of γ, Θ can be calculated as and using the equation (3), $\Theta = 37.16$. so, the net force is $6.45*10^{-4}$ N

If the discharge is calculated without considering friction [2] then, angle at which discharge starts is given by

$$\gamma = \sin^{-1} *(\frac{\_}{r_s} * \frac{1}{\omega^2}) \quad (11)$$

and putting prototype parameters into equation (11) the angle at which discharge starts 29.70^{0} .

The rate of discharge increases when the angle at which discharge happens from the chute increases.

By considering friction, the resisting forces increases and hence the angle at which discharge should begin is observed to be greater than the value obtained using the approach used in [2]. This can be seen in the Fig.9

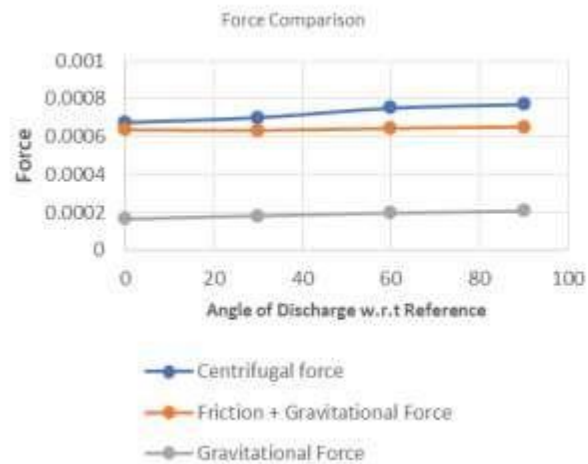

Fig.9 Comparison of forces

VI. CONCLUSION

Experimentally it is seen that with the increase in the angle of the chute end increases the discharge from the chute. Theoretical analysis is carried out to determine the angle at which centrifugal force will act on the maize grain and it can be observed that the angle remains constant during the whole process at fixed speed and sprocket diameter. The equation for the angle at which bucket elevator will begin to give discharge is calculated theoretically by force balance equation; and it was observed that as the speed drops below a certain point the discharge will not happen at all, similarly as the radius of the sprocket decreases the angle at which discharge begins goes higher.

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VIII. UNITS

- γ is the angle at which discharge starts with respect to reference
- ϴ is the angle at which component of centrifugal force acts
- $ϴ_1$ is the measured angle for force analysis with respect to reference
- A is the angle at which friction force acts = 16^0 (constant)
- B1, B2, B3 are the physical angles of the bucket, Where B1 is the physical angle of the bucket and is at the point of contact of the bucket and chain and then we see in the clock wise direction the interior angles are B2and B3
- I1 is the It's the angle made by the line passing through the origin (reference) and the point of contact of bucket with chain.
- I2 is the It's the angle made by the line passing through the origin (reference) and the imaginary line extended from the side of the bucket.
- I3 is the It's the angle made by the upper side of the bucket and the imaginary line extended from the side of the bucket.
- X and Y These are the coordinates of the grain or material put at the end of the bucket as shown in the figure with respect to the origin.
- g is the Gravitational acceleration [m·s−2] = 9.81
- m is the mass of the grain or material = 1kg/15432 grains = 6.48×10^{-5} Kg
- μ is the is the coefficient of friction which is between corn grain *(with the moisture content of 17.06% which is also called dry kernel)* and Iron surface. i.e. μ = 0.741
- r is the the distance of the grain from the reference point = 162mm
- h it's the height provided to the base of chute to increase the angle of chute
- L is the base length of the chute arrangement = 340 mm.

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